



**HAL**  
open science

## **FEMU based on Levenberg-Marquardt algorithm to identify creep behavior of Zircaloy-4 fuel rods under LOCA conditions**

Marwa Moula, Damien Campello, Nicolas Tardif, Marie-Christine Baietto, Michel Coret, Jean Desquines

### ► To cite this version:

Marwa Moula, Damien Campello, Nicolas Tardif, Marie-Christine Baietto, Michel Coret, et al.. FEMU based on Levenberg-Marquardt algorithm to identify creep behavior of Zircaloy-4 fuel rods under LOCA conditions. ICEM17, Jul 2016, Rhodes, Greece. hal-01863179

**HAL Id: hal-01863179**

**<https://hal.science/hal-01863179>**

Submitted on 28 Aug 2018

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

## FEMU BASED ON LEVENBERG-MARQUARDT ALGORITHM TO IDENTIFY CREEP BEHAVIOR OF ZR-4 FUEL RODS UNDER LOCA CONDITIONS

M. Moula<sup>\*</sup>, D. Campello<sup>\*</sup>, N. Tardif<sup>\*</sup>, M.-C. Baietto<sup>\*</sup>, M. Coret<sup>1</sup>, J. Desquines<sup>2</sup>

<sup>\*</sup> *Université de Lyon, CNRS, INSA-LYON, LaMCoS UMR 5259, 20 Avenue Albert Einstein, F69621 Villeurbanne Cedex, France*

**Abstract:** A custom experimental setup has been designed to investigate the secondary creep behavior of Zircaloy-4 fuel rods under Loss Of Coolant Accident (LOCA) conditions. Creep test are ran at elevated temperatures (from 700 to 900 °C) and the fuel rods are internally pressurized from 10 to 50 bars. The setup induces a non-uniform axial temperature profile. Three stress loadings are applied in a single test. Thermal and steady-state creep-rates are calculated from these experiments. A Finite Element Model Updating (FEMU) based on the Levenberg-Marquardt algorithm is proposed to identify a five power creep law behavior. Preliminary results about the creep behavior of as received Zircaloy-4 fuel rods are here presented.

### 1. Introduction

Since the nineties, the contact-less techniques are preferred to perform kinematics or thermal measurements in the field of experimental mechanics. Full field measurement techniques such as Digital Image Correlation [1], Infra-Red (IR) or Near IR (NIR) thermography grants a way to process thermal mechanical tests (see [2]). These experimental techniques are often correlated to finite element model to identify material behavior laws as proposed by Réthoré et al. in [3]. Finite Element Model Updating is one of the most used methods to solve the inverse problem of solid mechanics. The Levenberg-Marquardt Algorithm [4] (LMA) combines the gradient descent and the Gauss-Newton methods. It needs to run several finite element calculation (as much as the investigated parameters) at each iteration. It can be time and resources expensive.

In our study case, high temperature creep behavior of Zircaloy-4 can be modeled using eq. (1), as explained by Hayes et al. in [5].

$$\dot{\epsilon}_{ss} = A \cdot \sigma^n e^{-\frac{Q}{R \cdot T}} \quad (1)$$

The steady-state strain rate  $\dot{\epsilon}_{ss}$  depends on the true stress  $\sigma$  and the temperature T. The stress exponent n, the activation energy Q and the multiplicative coefficient A have to be determined.

### 2. Results

The Zr-4 specimen are 90 mm long, 0,57mm thick and their outer radius is 4,75mm. The region observed by cameras during tests is 20 mm long. The steady-state creep-rate distribution along the axial direction experimentally determined from different circumferential positions are extremely similar (see [6]). An axisymmetric model is thus chosen.

Finite Element calculation are performed using the commercial software Abaqus. The LMA has first been validated using numerical tests data. The thermal mechanical loading applied is the same than in the real tests. Specimen is heated up to the set temperature, then it is internally pressurized and the set pressure is maintained. Ballooning is occurring with the creep. The FEMU based on the LMA has first been performed using the radial displacements as numerical tests data. In this case, the temperature was considered uniform. Q is considered as a constant.

<sup>1</sup> GeM (UMR 6183), Ecole Centrale de Nantes, Nantes, France

<sup>2</sup> IRSN/PSN-REX/SEREX/LE2M, Saint Paul lez Durance, France

$A$  and  $n$  are the only parameters to be identified. The ratios of the simulated and “experimental” parameters are plotted versus the number of iterations in Figure 1. The real parameters are well determined.

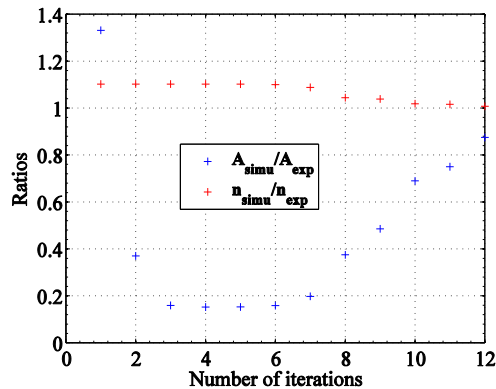


Figure 1: Validation of the FEMU method for the test configuration

The experimental data are now available. The thermal distribution experimentally determined is impeded using a UTEMP. Three internal pressures are investigated in a single test. The objective function minimized by the LMA is based on the three steady-state creep-rates profiles measured along the region of interest. The five power law should be identified with a single test configuration for the temperatures measured in the region of interest.

Tests on as-received Zr-4 claddings for temperature ranging from 775 °C to 850°C have been performed under inert atmosphere. The behavior laws accurately identified by the methodology proposed in this paper will be presented.

### 3. Conclusions

A LMA is performed to identify a five power law modeling the thermal mechanical behavior of as-received Zr-4 under LOCA conditions from experimental data. Test have been simulated using an axisymmetric model. The LMA and FEMU algorithm have been preliminary validated using numerical test data. Real tests are now simulated and creep behavior parameters will be presented in July for as-received Zr-4 under LOCA conditions.

### Acknowledgements

The study was performed in the framework of the PERFROI ANR project (n° ANR-11-RSNR-0017-01). The authors would like to acknowledge all the participants of the project: EDF, IRSN-SEREX, LEMTA, Ecole Centrale of Paris.

### References

- [1] M. Sutton, W. Wolters, W. Peters, W. Ranson, S. McNeill, Determination of displacements using an improved digital correlation method, *Image and vision computing* 1 (3) (1983) 133–139.
- [2] A. Maynadier, M. Poncelet, K. Lavernhe-Taillard, S. Roux, One-shot measurement of thermal and kinematic fields: Infrared Image Correlation (IRIC), *Experimental Mechanics* 52 (3) (2012) 241–255.
- [3] J. Réthoré, T. Elguedj, M. Coret, P. Chaudet, A. Combescure, Robust identification of elasto-plastic constitutive law parameters from digital images using 3d kinematics, *International Journal of Solids and Structures* 50 (1) (2013) 73–85.
- [4] D. W. Marquardt, An algorithm for least-squares estimation of nonlinear parameters, *Journal of the Society for Industrial & Applied Mathematics* 11 (2) (1963) 431–441.
- [5] T. A. Hayes, M. Kassner, Creep of zirconium and zirconium alloys, *Metallurgical and Materials Transactions A* 37 (8) (2006) 2389–2396.
- [6] D. Campello, M.-C. Baietto, M. Coret, N. Tardif, J. Desquines, Thermo mechanical behavior of fresh zircaloy-4 under LOCA conditions, *Creep 2015*, Toulouse France, 31-4 June